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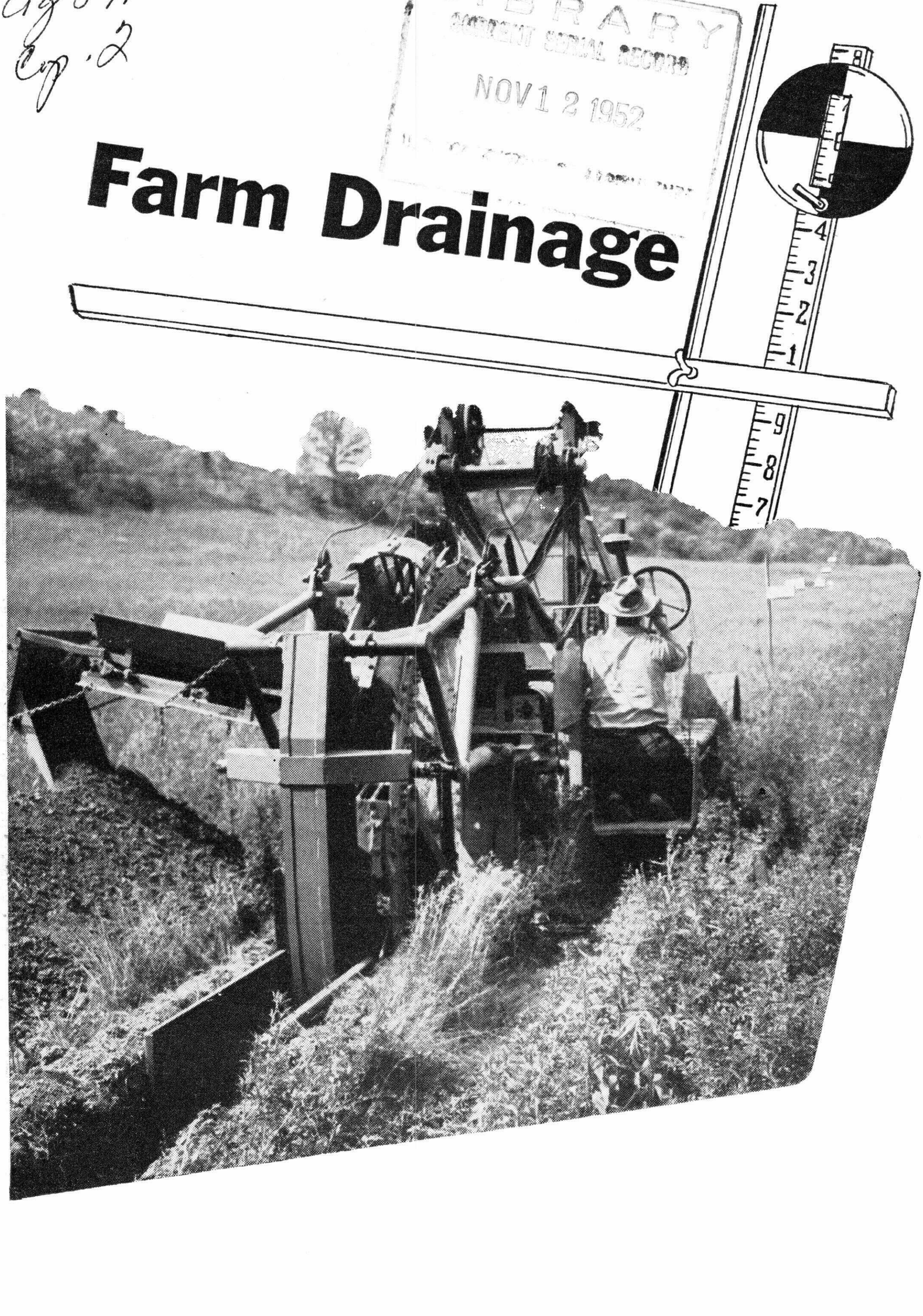
Farm Drainage



U. S. DEPARTMENT OF AGRICULTURE

Farmers' Bulletin No. 2046

Farm drainage is one of the most important and profitable practices of conservation farming. On thousands of farms, on millions of acres, fertile, level cropland too wet for profitable farming can, by means of drainage, be made to produce half again to double as much as it is now producing. Furthermore, by using level land to produce the staple row crops—corn, cotton, potatoes, tobacco—sloping land can be protected from erosion while in hay, pasture, or woods. This opens the way for more livestock and for a more diversified farming—one that protects and increases the fertility of the soil.

Much progress has been made in farm drainage in the 23 years since Farmers' Bulletin 1606, Farm Drainage, first came off the press. New drainage equipment and high-powered machinery have been developed. Research has found more effective ways to drain land and to farm drained land. Through soil conservation districts in every State of the Union, farmers can now get the use of modern machinery and the best available technical guidance.

This bulletin supersedes Farmers' Bulletin 1606, first published in 1929, and brings the information on farm drainage up to date. It is a practical guide for both farmers and engineers who deal with the problem.

Issued October 1952 Washington, D. C.

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FARM DRAINAGE

By Lewis A. Jones, *Chief, Division of Drainage and Water Control, Soil Conservation Service*

WHEN YOU PLOW, plant, and cultivate a field, and then—because of poor drainage—you get no crop, you not only lose the crop you hoped to grow, you also lose the fertilizer, seed, and labor you expended. Actually, a field that in some years produces a crop and in others does not, may be more of a liability to you than an asset.

Almost any farmer recognizes the cause when a crop is damaged because of poor drainage. But too often he assumes that the damage could not be helped and hopes that next year will be better. If the next year is better, he often forgets the poor years. But later he has more wet years. And he continues to lose crops because of them—that is, unless he does something about draining his fields properly.

Draining fertile, wet cropland is one of the important practices of conservation farming. It fits into conservation farming by which land is treated according to what it needs to produce the kind of crop it is best fitted to produce.

On many farms, the bottoms have the most fertile soil. But because they are wet part of the year they produce only part of the yield they could produce. Once drained, they will produce bumper row crops. Draining this flat land takes the pressure off steeper, poorer land that erodes easily when forced to produce such crops as corn, cotton, potatoes, and tobacco. The drained flat land can produce the row crops needed, and the slopes can be planted to close-growing crops or to grass (fig. 1).

The opportunity to get help with drainage problems has never been so good as today. More drainage equipment and high-powered machinery are now available to American farmers than at any time in our history. Through soil conservation districts, which farmers have now organized in every State of the Union, they can get the use of both modern machinery and the best technical guidance available.

It will probably be best to get an engineer or a Soil Conservation Service technician to help plan the drainage for your farm. Too many drainage lay-outs have failed for want of proper planning and handling. If you live in a soil conservation district, you may apply for this help to the supervisors of the district. If you are not in a district, apply to your county agricultural agent.

How Drainage Helps

A wet soil is a cold soil. This is because it takes much more heat to warm water than to warm soil. When soil is drained, air replaces the water that is drained away. It takes relatively little heat to warm this air. To grow well, plants, of course, need warmth and air in the root zone. The bacteria that change organic matter and fertilizer into something the plants can use require both air and warmth.

A wet soil is likely to be tight—or compact or dense. Plant roots cannot spread easily through such soil. Sweetclover and other soil-building crops will

not grow, so you cannot follow a balanced crop rotation. Liming, also, is often useless in a soggy soil.

After a wet soil is drained, you can work it earlier in the spring. Seeds germinate faster and you get a better stand. And plants do not drown out after a rain.

Sun and wind start drying a drained soil almost as soon as rain stops falling. Thus you can cultivate sooner after a rain. And you will not lose your crop at harvest time because of wet ground.

A properly drained field will not have wet spots, so you can farm more efficiently. You can plow, plant, and cultivate the whole field at the same time. You will usually get not only a bigger yield, but also a more even yield. And you will get it more cheaply because a drained field calls for less time and labor than one with wet spots.

Crops planted on land that needs drainage often "burn out." In a soil that is saturated nearly to the surface in spring and early summer, the plant roots spread out near the surface. Later, when summer droughts come, the water table falls below this root zone and the crop gets little moisture. In well-drained land, the roots go down deeper. Thus they can draw on deeper moisture, and the plants are better able to withstand summer droughts (fig. 2).

How Land Is Drained

Excess water can be drained from land either by open surface drains or by underdrains, usually tile.

Each method has advantages and disadvantages.

Open ditches occupy land. They are usually hard to cross with farm machinery. They choke up with weeds and silt and have to be cleaned. Unless they are deep they drain only the surface, not the soil. But their first cost is less than tile drainage. And for tight soils in humid areas surface drainage is usually necessary (fig. 3).

Tile drains, on the other hand, waste no land and do not interfere with farm

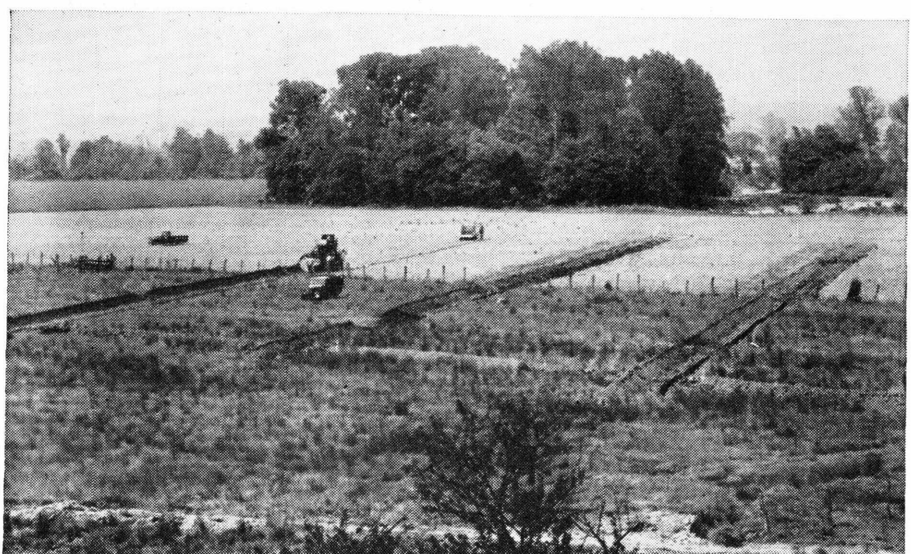

***Figure 1.*—Bottom land being tile drained as part of a conservation plan for a farm in Virginia. When the conservation treatment is complete on this farm, all the row crops will be raised on bottom land and the rolling land will be kept in grass or some other close-growing crop.**

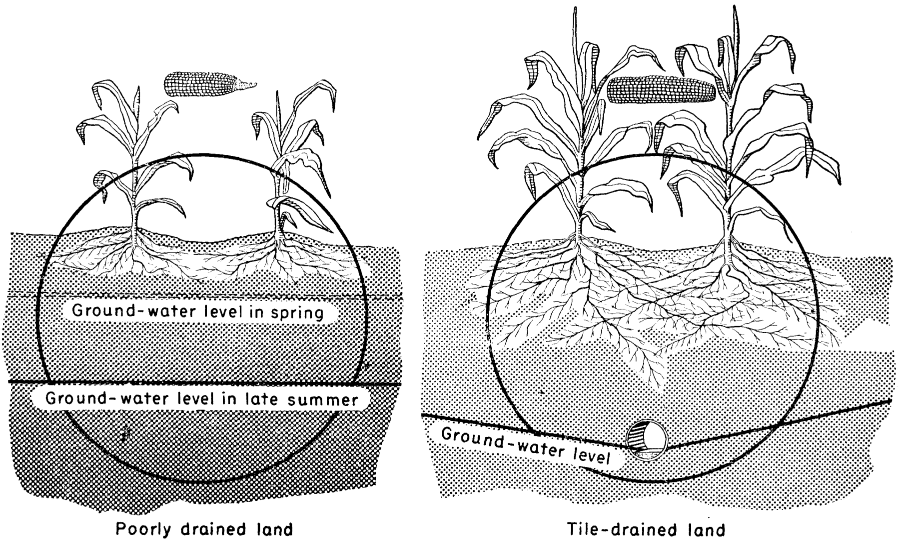

***Figure 2.*—Why land needs drainage. Plant roots cannot spread in a soil that is wet nearly to the surface. If the water table falls because of summer drought, the crop "burns out."**

operations. They need little care once they are installed. Since they drain the pores of the soil, roots of crops can spread. But usually tile drains require more cash outlay in the beginning. And they are not effective in some soils.

Planning Your Drainage System

Only conditions in your own area can determine the kind of drainage you need, and the method of doing the work. What is good in one place may not be good in another. Your soil, the ground slope, the crops you raise, and the value of your land must all be considered. Neighboring farms must also be considered. An adequate drainage system often involves a number of farms, sometimes a whole watershed. In such cases it is better to plan on a district basis rather than farm by farm.

Before planning a drainage system you need a detailed map of your land. First of all, you need to know whether your land can produce enough to make it worth while to install a drainage system—for drainage is expensive. The land-capability map made by the Soil Conservation Service as a basis for a farm conservation plan will give you this information. If you live in a soil conservation district you can ask your district supervisors for assistance.

The next thing you need to decide on is the outlet; that is, how the water will be carried away and where it will be discharged. Many farm drains have failed because of poor outlets.

Plans for successful farm drainage include plans for controlling erosion on the land, on ditches and spoil banks, and at outlets. They include plans for farming the drained land in crop rotations that will bring about good soil tilth, or structure. They also include plans for keeping the drains working. Farmers' Bulletin 2047, Maintaining Drainage Systems, gives details on how to keep drains working and also on how to repair drains that have failed.

Some simple drains you can locate by inspection. And if there is ample fall, you can determine a workable grade with a carpenter's level. But engineering instruments and techniques should be used for large areas. They should also be used wherever it is not certain that enough fall is available for all the drains.

Except for simple drains you should have a map that shows:

Boundaries and slopes of the areas needing drainage.
Existing drains.
Location and elevation of all swales and watercourses, knolls and ridges.
Location and elevation of possible outlets.
Area that will drain into each part of the system.

The drainage system can be laid out readily on this map; grades and sizes of the drains can be determined; and costs estimated.

After the drains have been laid out on the map, they can be staked out in the field. At this time, make any minor changes that are needed. The next step is to run levels along the lines of each of the proposed drains. Do this to determine accurately the grade or fall available for each. Then establish the grade to which the ditches or trenches must be dug. The most practical way to do this is to plot a profile of each drain and then determine the most economical adjustment that will give good drainage.

It is also practical to make soil borings to find out what kind of material you must dig through. If you find rock, hardpan, or quicksand, you should explore further. You may need to change the location of your drain. Or, if it is an open ditch, a change in size may be sufficient.

Most farmers will need the help of a drainage engineer for work of this sort.

The Outlet

A great many farm-drainage systems have failed because of poor outlets. Ordinarily water is discharged by gravity into a natural watercourse or into a public ditch, such as one constructed by a county or a drainage district. But it may be a private drain—your own or your neighbor's.

If you are planning to use an outlet constructed or improved by another

***Figure 3.*—Open bedding ditches for draining land in Texas. Heavy, impermeable clay subsoil makes tiling impractical.**

farmer or by a group of which you are not a member, learn upon what terms you may use it. Many States have laws under which an individual landowner can obtain drainage outlet across the land of another by paying proper damages.

Where several landowners will be benefited by work to be done on an outlet, they may find it best to organize a community enterprise under the State drainage law. If only a few farmers will be affected, an agreement signed by all of them may be sufficient. This agreement should specify where the drain is to be located and how the cost is to be apportioned. It should also state how the other business matters will be managed. Group action has been made easier and more effective in many areas where farmers have organized soil conservation districts.

Your outlet must be large enough. It must carry away the water brought to it promptly enough to drain your own land and it must prevent injury to any lands of your neighbors. Its size depends on a combination of many factors—the rainfall, the area of the watershed, the slope, the soil, the vegetation. Calculation of the right size is too involved for general discussion in this bulletin. If larger drains are required than those for which capacities are given on pages 9 and 22, a drainage engineer should be employed or assistance should be obtained through the local soil conservation district.

Every outlet must be deep enough to permit inflow from the tributary drains. Where the land is to be tile drained, the outlet should be at least 5 feet, preferably 6, below ground surface. The water, except for short periods after storms, should be at least 4 feet below ground surface.

An outlet for tile drains should carry the water reaching it without submerging the tile for long after a heavy rain. The ideal outlet permits free flow from the tile at all times.

Water can be discharged by pumping instead of by gravity. But pumping is usually too costly for small

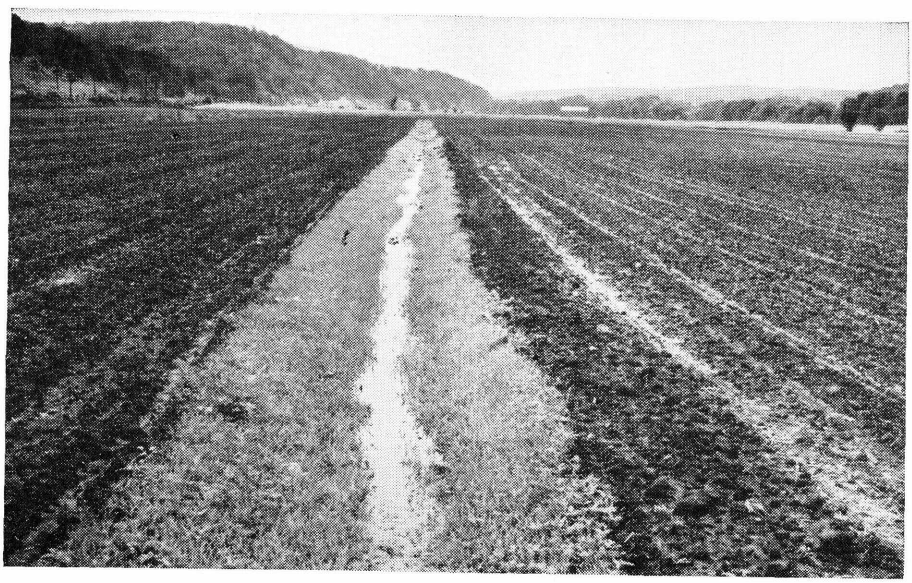

***Figure 4.*—Sodded field ditch in Virginia. This field is Class II land, very good level land that needs drainage to produce good crops.**

Figure 5.—**V-shaped collecting ditch in Maryland. The banks are seeded to lovegrass.**

drainage systems. It often proves profitable, however, for rather large undertakings, such as an organized community enterprise, or for a farm growing high-value crops. In any case, pumping for drainage is costly. It should be planned only with competent engineering direction.

Surface Drainage

With surface drainage, water on your fields is removed through open ditches (fig. 4). These field ditches empty into larger and larger ditches (fig. 5) until they reach some natural or artificial watercourse that carries the water away without damage to the land.

Where the land is somewhat rolling, you may be able to get surface drainage by shallow field ditches that follow the depressions. You can determine the locations by observing where water is standing on the ground after a heavy rain. Then the ditches can be dug or plowed at a later time—when men and equipment are not doing other work. In this way you can gradually bring the low spots of the field into cultivation. In a few years, with only a small outlay of cash, you can greatly improve the drainage condition of your land. But remember, shallow ditches merely remove surface water. If your land also needs soil drainage, you must dig numerous and comparatively deep ditches, or construct underdrains.

Ditches that follow the low land may be very crooked. Often you will do better to cut the ditch through a low ridge or knoll and so avoid a sharp bend. Changes in direction should be made by easy curves, in order to prevent erosion of the ditchbanks. You can lay these curves out "by eye."

Field Ditches

Field ditches may be either narrow with nearly vertical sides or V-shaped with flat side slopes. V-shaped ditches

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have the advantage of being easy to cross with large machinery. Narrow ditches are most common where large farming machinery is not used much.

Land occupied by the narrow, steep-sided ditches cannot be cultivated. Where many of them are required you lose a considerable area to cultivation.

Neither can large V-shaped ditches be cultivated, but many can be planted to grass and mowed for hay. Where very closely spaced field drains are needed, V-shaped ditches can be made very shallow and broad and then cultivated with the rest of the field.

In level areas you may need to install a collecting ditch along one side of the field and then construct shallow V-shaped ditches discharging into the collecting ditch. The field ditches should be laid out parallel and spaced 50 to 150 feet or more apart as required by the soil, surface conditions, and crops to be grown. They should be 12 to 24 inches deep, depending upon the depth of the collecting ditch.

Farming operations should be parallel to the field ditches. In plowing, establish back furrows midway between the ditches and turn all furrows toward the middle. This will give each land a slight crown and will keep the ditches open (figs. 3 and 6).

If this practice is followed several years, the land acquires a considerable crown. Therefore, it is best not to use it where land should be kept as level as possible. This is especially true where field drains supplement tile drains.

Size of Ditches

The area that a ditch will drain satisfactorily depends on how quickly water runs into it, its size, its grade (precisely, the slope or rate of fall of the water surface), and its irregularity. This irregularity is affected by both the roughness of the ditch section and the debris and growing vegetation in the ditch. How quickly water runs into it depends on how much rain falls, and when, and on the land slope and the condition of the soil and the plant cover.

Field ditches and outlet ditches to drain up to 600 acres of level to gently sloping land should be large enough to remove at least 2 inches of water from

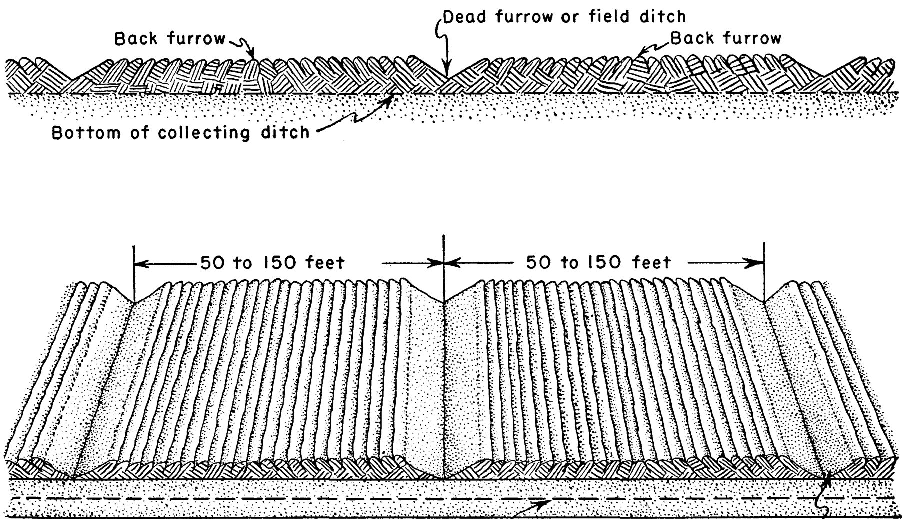

Figure 6.—**How to plow a field divided by field ditches.**

TABLE 1.—*Areas of level to gently rolling land that can be drained by* V*-shaped field ditches running full*

[Computed by Manning formula, $n=0.045$]

Depth of ditch (feet)	Top width of ditch	Side slopes	Excavation per 100 feet	Area drained by ditches with fall per 100 feet of— 0.02 foot	0.04 foot	0.06 foot	0.08 foot	0.1 foot	0.15 foot	0.2 foot	0.3 foot	0.4 foot	0.5 foot
	Feet		*Cubic yards*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*
1.0......	6	3 to 1	11.1	10	14	17	20	22	28	32	39	45	50
	8	4 to 1	14.8	13	19	23	27	30	37	43	53	61	68
1.5......	9	3 to 1	25.0	30	42	52	60	67	82	94	116	134	149
	12	4 to 1	33.3	40	57	70	81	90	110	127	156	180	202
2.0......	12	3 to 1	44.5	64	91	111	128	143	176	203	249	287	321
	16	4 to 1	59.3	87	123	151	174	194	238	275	338	390	436

TABLE 2.—*Areas of level to gently rolling land that can be drained by small flat-bottom ditches with 2-to-1 side slopes, running full*

[Computed by Manning formula, $n=0.045$]

Depth of ditch (feet)	Bottom width of ditch	Top width of ditch	Excavation per 100 feet	Area drained by ditches with fall per 100 feet of— 0.02 foot	0.04 foot	0.06 foot	0.08 foot	0.1 foot	0.15 foot	0.2 foot	0.3 foot	0.4 foot	0.5 foot
	Feet	*Feet*	*Cubic yards*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*
1.5......	4	10	38.9	57	81	100	115	129	157	182	223	258	288
	6	12	50.0	78	110	135	156	174	214	247	302	350	390
2.0......	4	12	59.3	102	145	177	205	229	280	324	397	459	[1] 510
	6	14	74.1	135	191	234	270	301	369	426	525	604	[1] 700
2.5......	4	14	83.3	162	230	282	325	363	445	515	630	[1] 800	[1] 970
	6	16	101.8	209	296	362	419	467	570	675	965	[1] 1,240	....

[1] Velocity is within range 2.6 to 3.0 feet per second.

the area in 24 hours. Tables 1 and 2 show the areas that small V-shaped, and flat-bottom ditches will drain at grades up to 0.5 foot per 100 feet. In computing these acreages we have assumed that the ditches will be kept reasonably free of obstruction. That is, they will be kept free of debris and growing brush or tall grass and weeds. When planning ditch sizes for hilly land, reduce the acreages tabulated by 25 to 50 percent unless the area is heavily wooded.

Flowing water has power to erode channels as well as land surfaces. This power increases with the velocity of flow, but very much faster.

In many cases it is practicable to keep a low velocity by constructing the ditch in sections having less fall than the natural slope and connecting those sections with drop spillways (p. 15). Drop spillways are recommended wherever the average velocity of the flow will exceed 2½ feet per second in sand or sandy loam, 3 feet per second in silt loam, 3½ feet per second in sandy clay loam, 4 feet per second in clay loam, and 5 feet per second in stiff clay or fine gravel. None of the velocities computed for the ditches in table 1 exceeds 2½ feet per second. Those in table 2 exceeding that velocity are marked.

Figure 7.—**Tractor applying fertilizer in a field ditch in Illinois. Side slopes are 3 to 1, horizontal to vertical. In the background is a concrete drop-spillway dam.**

Side Slopes

Field ditches of the V-shape designed to be crossed by farm machinery should have side slopes of 3 to 1 (horizontal to vertical) or flatter (fig. 7). Narrow field ditches may have sides as nearly vertical as will resist frost action and erosion by water running down the sides.

For outlet and collecting ditches in clay and clay loam soils, 2-to-1 side slopes are best. In some areas 1½-to-1 slopes have been satisfactory and in many even 1-to-1 slopes have stood up well.

Look at existing ditches in your neighborhood to learn what is desirable there. Vertical slopes can be used in rock. In hardpan and loose rock ½-to-1 slopes generally are satisfactory. In peat and muck soils, ditchbanks nearly vertical have stood better in many places than flatter slopes.

Occasionally there may be some unusual condition that will affect the stability of ditchbanks. Such might be a restricted right-of-way for the ditch where the excavated material must be placed so close it will put extra weight on the ditchbank.

Berms

The berm is the strip of ground between the edge of the ditch and the nearer edge of the waste or spoil bank. One of its purposes is to avoid adding the weight of excavated earth at the edge of the ditch. Too much weight would be likely to cause caving of the bank. Another is to give room for men and machinery to work when clearing the channel of sediment, debris, or growing plants.

You need a clear width of at least 10 feet where spoil banks are not leveled. On large outlet ditches the berms should be wider, usually 15 to 20 feet. How wide depends on the side slopes of the ditch and the equipment to be used for maintenance work.

If the ditch is dug with a ditching plow or grader the excavated earth can be moved back from the edge of the ditch with the same machine.

Staking Out Ditches

Staking out is the first step in constructing an open ditch. To do a good job and get the most effective drainage, you need several stakes for different purposes. You need some to establish the grade; others to mark the center line of the ditch. "Slope stakes" mark the top width of the ditch. "Berm stakes" mark the toe of the spoil bank. All of these stakes are included under the general term "construction stakes." These stakes, their uses, and the names they are commonly called are shown in figure 8.

First set stakes along the center line every 100 feet where the ditch is straight and every 50 to 25 feet on curves. Then set grade stakes to one side of the ditch at 100-foot or shorter intervals with their tops at a uniform height, usually 5 feet, above the grade of the ditch bottom. Check these grade stakes by sighting to be sure that their tops line up properly.

To be sure the ditch is excavated to grade as construction work progresses, the depth of the ditch can be checked by sighting over the top of a gage stick held in the bottom of the ditch. The gage stick should have a length equal to the distance the tops of the grade stakes are set above the established grade of the ditch. When the ditch is excavated to grade, the top of the gage stick will be in line with the tops of the grade stakes.

On ditches to be constructed by dragline excavators, set slope stakes on each side of the center-line stakes to mark the top of the ditch. Set berm stakes to show the toe of the spoil bank. The tops of the berm stakes should be at the maximum height at which the earth may be deposited in the spoil bank. Bottom stakes should be set between each pair of slope stakes just as soon as the excavating machine has passed. They will guide the machine operator in working ahead. A good job of staking out is necessary to get a uniform ditch with even banks.

Spoil Banks

Place the "spoil" excavated in making the ditch back of the berm stakes. The banks should not be so steep that rains will wash the material back on the berm. And there should be openings through the spoil banks to let surface water into the ditch. You can save work by staking out the openings before the ditch is constructed and thus avoid putting the spoil where it will have to be rehandled.

Where the land is to be cultivated, pastured, or used as meadow, the spoil banks should be "leveled." You can do this with a tractor equipped with a bulldozer, or with a tractor and road grader, or with a carry-all scraper. At the same time you can smooth up the field, using the spoil to fill in slight

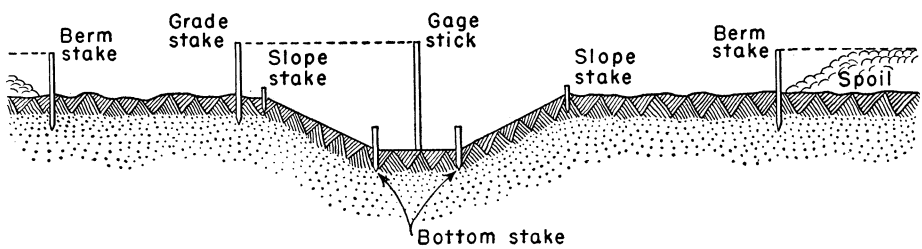

***Figure 8.*—Cross section of ditch showing the location of the different kinds of construction stakes.**

Figure 9.—Constructing shallow V-shaped ditch with tractor and grader.

depressions. The resulting side slopes should never be steeper than 4-to-1. More nearly flat slopes are desirable, but they increase the amount of earth to be moved. If the ditch is excavated with a dragline, the leveling work can be reduced by requiring that the machine spread the spoil so that a tractor can operate on the top.

Spoil banks with 4-to-1 side slopes can be cultivated readily, or mowed for hay, or fenced and pastured. But keep stock off ditchbanks and berms when the ground is wet.

Ditching With Machinery

Where the ground is relatively free of stumps and large stones and is dry enough to afford good traction, V-shaped ditches can be constructed economically with a tractor and grader, with a plow and V-drag, or with tractor and a small ditching plow (fig. 9). These machines are drawn back and forth until the ditch is as large as you want or as large as the machine can dig.

The narrow-type ditches, usually 1½ to 2½ feet deep, are usually dug with hand tools. You may find an ordinary turning plow helpful in loosening the topsoil, or in cutting the edge of the ditch where there is heavy sod.

Under most conditions a small dragline excavator is the best machine for digging ditches deeper than 3 feet. Buying such a machine would not pay for a single farm job of ordinary size. Such work usually is done under contract by a man or company that makes it a business. In many soil conservation districts, farmers cooperate in renting or buying power machinery for ditching (fig. 10).

Ditching With Dynamite

Ditching with dynamite is possible under almost any condition. But, usually, it is economical only for making small ditches or cut-offs in stream channels, in soils other than gravel and dry sand. Dynamite is best suited for ditching in soft ground where heavy machinery would bog down, and on jobs where the amount of earth to be moved is not enough to pay for a

power-excavating machine. Ideal for dynamite ditching is a saturated sedimentary soil that is firm, but not stiff, and is free from stumps and large roots. Many excellent ditches have been blasted under conditions different from these, but at greater cost.

You can use dynamite to advantage on a ditch about 3 feet in depth and 8 feet in top width. But on larger ditches the cost per cubic yard of earth moved increases rapidly with the size. Where conditions permit the use of ditching machines, the cost is usually less than if dynamite were used. It is, however, usually cheaper to dig ditches with dynamite than with hand labor.

To blast a ditch less than 10 feet wide with dynamite you place a number of small charges in holes along the center line. For wider ditches, place the charges in two or more rows.

Charges are exploded by one of two methods:

1. The propagation method (used in saturated soils). Charges are so closely spaced that the detonation of one explodes the next, and so on through the series. You can prime the starting charge with a blasting cap and fuse, or with an electric blasting cap connected to an electric blasting machine. The latter method is safer because fuses frequently fail to burn properly and serious accidents sometimes result.

2. The electric method. Each charge is primed with an electric blasting cap connected by wires that lead to an electric blasting machine. This method is more expensive than the propagation method and is seldom used where soil conditions permit use of the other.

Straight or nitroglycerin dynamite is usually used for ditching. It is made in several strengths designated by percentages. For explosion by the propagation method, 50-percent strength is usually satisfactory.

The size of the charges, the depth, and the distance apart depend on the conditions in each case. For each

***Figure 10.*—Ditching machine owned by the Virginia State Conservation Committee and rented to the Thomas Jefferson Soil Conservation District. The machine requires two operators. The District rents it for $12 an hour.**

size of charge there is a definite depth which will give a broad, clean-cut, U-shaped ditch and also the maximum of excavation per pound of explosive. If you place a charge too deep for its strength, loose dirt will be left on the sides of the ditch. If you put it too shallow, full power of the dynamite is not used.

The effective size of charge and the spacing must be determined by trial for each set of conditions. For a ditch 3 feet deep and 8 feet wide on top, in a saturated soil, the propagation method usually requires charges of one stick of 50-percent straight dynamite each, in holes 30 inches deep and 18 to 24 inches apart.

The Ashley core is a useful tool for getting dynamite into soft ground, and it may be made by a blacksmith (fig. 11). It operates on the principle of a pile driver. A metal core with a pointed end is worked up and down inside a shell to make a hole for the dynamite. The metal core is then

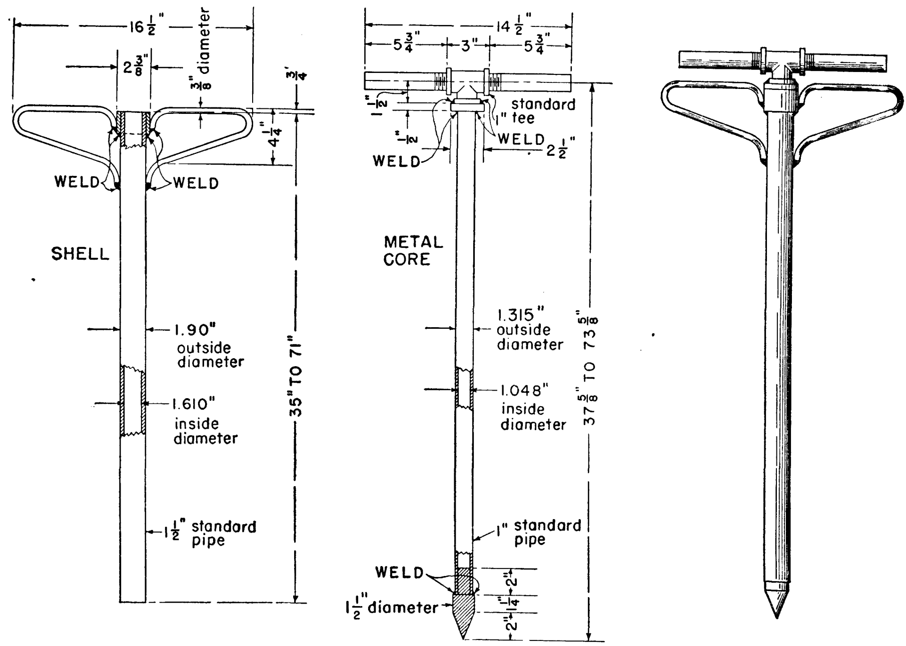

***Figure 11.*—The Ashley core punch, a useful tool for getting dynamite into wet soils that tend to cave or for getting it under stumps and boulders.**

withdrawn and the dynamite is pushed in place with a wooden stick. You should never use the metal core or any iron bar to push dynamite. Fatal accidents have been caused by attempting this. Always use wood for tamping sticks of dynamite.

The cost of ditch excavation by dynamite varies greatly. Under favorable conditions you can blow out 1 to 1½ cubic yards of earth with a pound of dynamite. You need very little labor for dynamite ditching, as four men can load and shoot about 600 linear feet of single-row charges in a day. But you do need to remove debris and smooth the sides and bottom of the ditch with shovels after blasting. This work should be done as soon as possible and, if done promptly, it should not cost more than 2 to 4 cents per linear foot of ditch.

You can get from any of the manufacturers of explosives detailed directions for loading and firing explosives in ditching and for handling and storing dynamite. Many States require a permit before a person may use explosives. No one should undertake dynamiting until trained by a competent blaster.

Structures Used With Open Ditches

Water flowing into field ditches and from field ditches into collecting ditches or main ditches is apt to erode the banks. In fact, wherever a ditch joins a deeper ditch there is apt to be erosion unless the water surface in the deeper ditch is always as high as in the tributary. Erosion once started is likely to continue, and to start gullies in the field. The eroded material will be dropped in lower parts of the drainage system, obstructing the flow. Removing this material is costly. Fortunately, there are fairly easy and inexpensive ways to protect your fields

and ditches against erosion. The cheapest and easiest way is to make a short grassed waterway or flume.

Flumes

The grassed flume—sometimes called a chute—provides an economical means of safely admitting water from a field ditch into a lateral or an outlet ditch (fig. 12). It is a broad channel lined with grass or other vegetation, sloping gently from the field to the ditch bottom. The bottom slope should not be greater than 6 to 1; 10 to 1 is better if your soil erodes easily or cannot readily maintain a dense cover.

You can use the same kind of flume where a shallow field ditch joins a main or outlet channel, provided you can get a dense enough grass cover. Make the bottom of the field ditch the same height as the bottom of the outlet for 5 to 15 feet back from the junction, before beginning the upward slope.

Occasionally, natural growth of vegetation will be sufficient to prevent serious erosion. But most flume channels must be seeded, sodded, or planted. A conservationist in your soil conservation district or your county agent can advise you on the kind of grass or other cover best suited to your land.

***Figure 12.*—A grass flume for getting water from a lateral ditch into a main outlet ditch without eroding the ditchbank.**

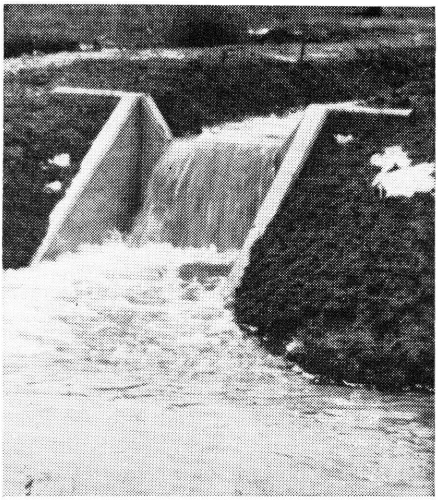

***Figure 13.*—Reinforced concrete headwall, or drop spillway, where flow from a field ditch drops into an outlet ditch. The apron between the wing walls is below low water in the outlet.**

Where grassed flumes will not prevent erosion, use a paved flume. Concrete and stones are the most common paving materials. It is advisable to place the toe of the slope of a paved flume 10 to 15 feet back from the bottom of the larger ditch. This will decrease the danger of silting the main ditch.

Headwalls or Drop Spillways

In some places a flume between ditches might extend back into cultivated land. It may be preferable to make such a drop by a headwall at the bank of the larger ditch, even at a greater cost. A headwall of reinforced concrete is shown in figure 13. Brick or stone masonry sometimes is used. Headwalls can be used anywhere in a

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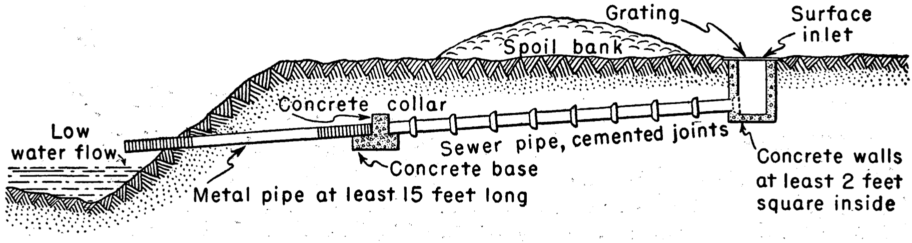

***Figure 14.*—Pipe outlet under spoil bank to carry surface flow from low ground to drainage ditch. The water enters through a concrete inlet back of the spoil bank.**

ditch to drop the flow from one level to another. A headwall, or drop spillway, should extend well into the sides of the ditch in which it is built, and below the bottom of the outlet ditch, to prevent erosion around or under the structure. For the same reason, the ends must be built up above the highest flow.

To prevent undercutting, the structure usually must have an "apron" or floor for the water to fall on. The apron usually should have side walls (called wing walls) and a cut-off wall at the outer edge. In some cases, you can leave an opening through the spoil bank of the outlet ditch at some distance above or below the headwall to serve as an auxiliary spillway. During extreme floods some of the water can then overflow into the outlet channel. By this arrangement, you can use a smaller structure than would otherwise be safe.

Pipe Outlets

In some places a spoil bank, or perhaps a roadway prevents surface water from an adjacent field from reaching a drainage ditch. Here you can often use a small pipe outlet under the spoil bank or roadway (fig. 14). A concrete surface inlet at the low point of the field admits the water to a metal pipe, which carries the water to the drainage ditch.

A shallow **V**-shaped channel parallel to the ditch and above the spoil bank may be needed to collect the water from the field and carry it to the concrete inlet.

Water Gates

Wherever fences must cross an open ditch, you usually need a "water gate" or flood gate. This gate should keep livestock from passing under the fence and at the same time not catch any floating plants or trash that would choke up the ditch or cause cross currents that would damage ditchbanks.

A swinging gate, hung in sections from a cable or beam, answers both needs (figs. 15 and 16). When high water flows in the ditch, the gate swings forward and lets trash and floodwaters

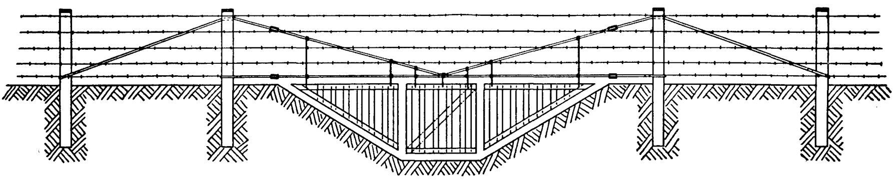

***Figure 15.*—A three-section watergate, swinging from a cable that can be tightened if it sags. The gate is designed to confine livestock but pass floating debris.**

***Figure 16.*—A four-section water gate across a drainage ditch that keeps animals in but lets trash through. Running water swings the gate forward and trash floats on down the channel.**

through. It closes when the water stops running.

To help keep a cable from sagging, the posts should be well anchored. Usually you also need a turnbuckle or some other device to tighten the cable if it does sag.

Underground Drainage

Underdrains drain the soil rather than the surface. They take out only excess water, not water that plants can use. That water is held in the soil by capillarity. The excess water flows by gravity into the drains and is carried through them to the outlet. Underdrains have definite advantages over surface drains. They occupy no land surface. And they do not harbor weeds or interfere with farming operations.

Tile is the common material used for underdrainage. Poles, brush, stones, and lumber have also been used. Where properly installed, they provide fair drainage for a time. But usually they work well for only a few years because they become obstructed by sediment or by decaying wood.

Another kind of underdrain that has been satisfactory in some localities is the mole drain. Mole drains are unlined channels through the ground that operate similarly to tile drains. They are made with a special moling machine (fig. 17). This type of drain is most often used in clay, clay loam, or organic soils. It is not feasible in loam or sandy soils, or in rocky soils, or where there are stumps and other obstructions. Usually you should get advice of an experienced drainage engineer or your soil conservation district technician before constructing mole drains.

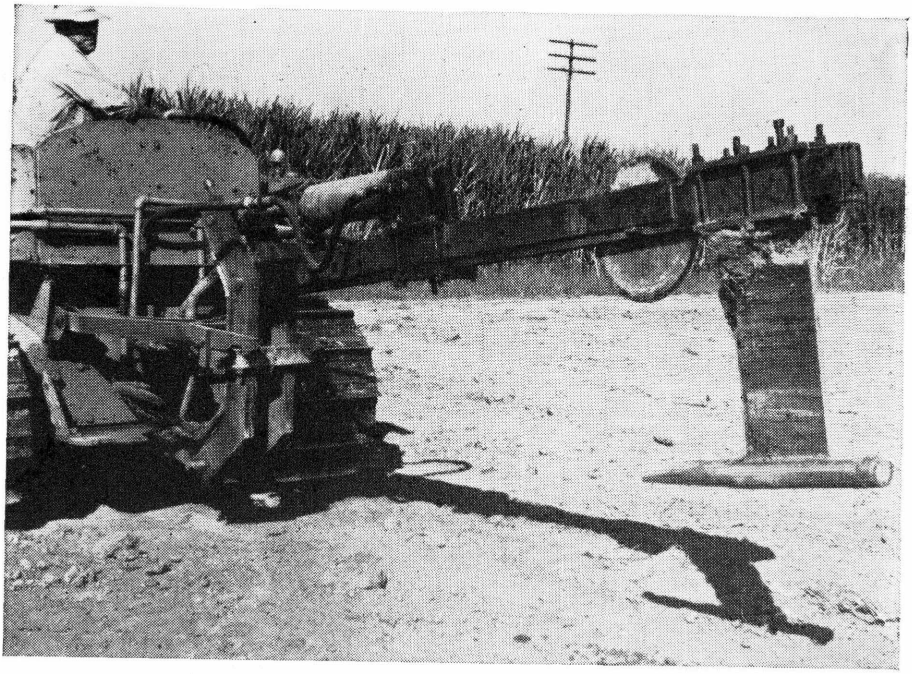

Figure 17.—**A moling machine elevated to show the vertical blade and attached steel mole that forms the unlined drain. On the beam of the machine is a hydraulic cylinder operated from the tractor that pulls the machine. From the driver's seat, the operator can raise or lower the mole to make any adjustments needed because of uneven ground surface.**

Tile Drains

The tile drain is undoubtedly the best underdrain. When properly selected and installed, it becomes a permanent improvement which needs only slight care afterward.

Water moves into tile drains by gravity. It enters through the joints between the tiles, not through the walls as many people suppose. The walls of most porous tile absorb water rapidly until saturated, but little water passes through them. Thus, porous tile gives no better drainage than impervious tile. Moreover, porous tile is likely to be soft and easily broken or crushed.

Locating Tile Drains

The lay of the land and the location of the outlet largely control the placing of tile drains. If your land is rolling, you may be able to drain your farm by lines of tile laid in the natural water courses, with extra branch lines as needed in wide wet areas. Such an arrangement of drains is known as a random system (fig. 18).

If your land is uniformly too wet for cultivation it is better to construct a so-called complete system of tile drainage (fig. 19). The main drains follow generally the natural watercourses of surface flow; the laterals are laid in parallel lines or groups of parallel lines under the whole area. The laterals should be straight and run in the general direction of greatest slope. They should be laid at such intervals and at such depths as the soil requires.

A system of short mains with long laterals is most economical. The mains

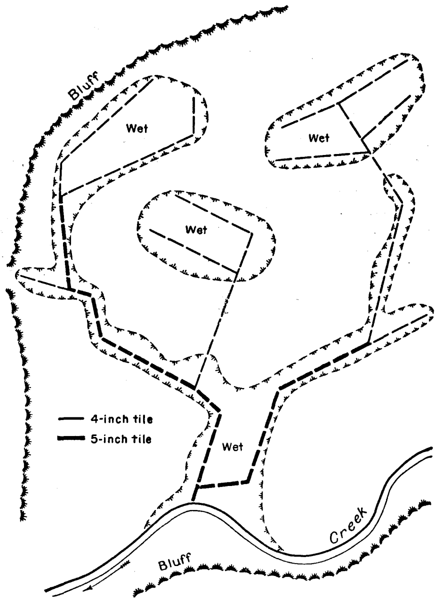

Figure 18.—**Plan for a random system of tile drainage. Main drains are to be laid in the natural waterways and smaller branch lines in large wet areas.**

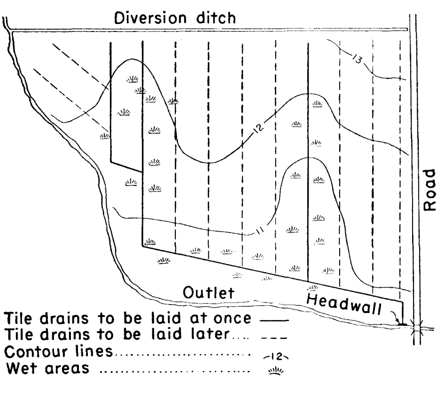

Figure 19.—**Plan for a complete system of tile drainage. Random drains are to be installed at once in wettest parts of field and parallel lateral drains to be installed later.**

drain the land for a distance on each side; across this drained belt the laterals serve only to carry their water to the main. Each main should serve as large a portion of the area as possible, to keep the number of outlets at a minimum, for outlets always require more or less attention if the drains are to operate satisfactorily.

If a whole field would be benefited by tile drainage and you do not have enough money to construct a complete system, you can drain the parts that need it most and leave the remainder of the work until later. Study the results obtained from the first drains you install. Then you can determine more surely where to lay additional drains. When you plan a drainage system in this manner, keep in mind the requirements of the complete system so that the random lines will be large enough and deep enough to take the flow from future laterals. In this way you will get the best results from the money expended, and your increased returns from the drained land can be used for completing the improvement.

When the area to be drained is large and nearly level, a drainage engineer should be obtained to survey the area, design the improvements, stake out the drains, and check on their construction. Where the land has plenty of fall and the tracts to be drained are small, you can locate your drains during wet periods and construct them whenever the general farm work and the weather permit.

Draining Seepy Hillsides

Wet areas along hillsides usually are caused by an impervious layer of soil that stops the downward flow of the water and forces it above ground. This keeps the soil too wet for cultivation. You can correct this condition by laying a tile drain **above** the line

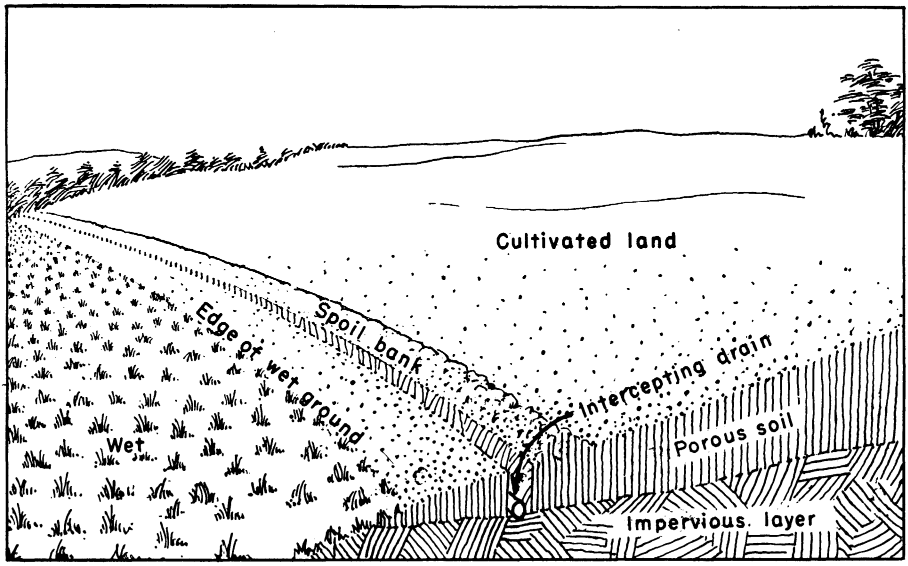

Figure 20.—**Proper location for an intercepting drain.**

where the ground becomes wet. Place it deep enough to intercept the water flowing along the top of the impervious layer (fig. 20). •Set the tile a few inches into the impervious layer and backfill with gravel. The drain should run across the slope as nearly parallel to the seepy place as possible, with a continuous slight fall toward its outlet.

Depth and Spacing of Tile

Tile drains should be spaced so as to lower the ground water enough for good plant growth within 24 hours after a rain. They lower the ground-water surface in a curve that is lowest at the drains and ordinarily highest midway between them (fig. 21).

The rapidity with which drains lower the water depends on how easily water moves through the soil. The soil's texture and structure affect this rate.

In sandy land you can place the drains deeper and therefore farther apart than in clay land.

Some clay soils have a tendency to crack and this greatly helps under-drainage. Water flows more readily through the cracks.

In tight clay soil the movement of water is very slow, and tiles must be placed at less depth and closer together than in soil with more open texture.

In clay and clay loam soils you may have to place tile 40 to 70 feet apart and 2½ to 3 feet deep. No tile should be laid less than 2½ feet deep; that is, the bottom of the trench should be at least 2½ feet below the ground surface. Large tile should be laid deeper. Cover the tile with at least 24 inches of earth to prevent breakage by heavy machinery.

In silt loams you can often space tile 60 to 100 feet apart and 3 to 4 feet deep.

In sandy loams, tile spaced 100 to 300 feet apart and 3½ to 4½ feet deep may give good results. A spacing closer than 50 feet usually makes drainage too costly unless you are to use the land for truck or other high-value crops.

All tile should be laid deep enough to be free from frost damage.

Size of Tile

The proper sizes of tile for the mains and submains of a system depend on many things. In the first place, where surface channels carry off a large part of the water during a storm, tile drains have to provide for only the part that seeps into the soil.

Also, because water passes through open soil more rapidly than through tight soil, it reaches drains faster through open or more permeable soil.

Then, too, the less the grade or fall, the larger must be the size of tile. The capacity of a tile line is twice as great at 4 inches fall in 100 feet as at 1 inch.

And finally, the needed size depends on the size of the drained area. Other conditions being the same, the required capacity of a drain is nearly proportional to the acreage from which the water comes.

Four-inch tile is the smallest you should use in land drainage. Five-inch tile will serve better and should be used if it will not cost much more than the other. The 5-inch tile has nearly twice the capacity of the 4-inch and is less likely to become clogged by sediment getting into the line.

Where no surface water will get into the tiles, tile systems in ordinary loamy soils should be able to remove 3/8 inch of water over the drained area in 24 hours. If you have one of the more permeable soils through which water passes rapidly, such as a very loose sandy loam, your main tile drains should remove 1/2 inch in 24 hours. Where much surface water will be admitted, these drains should be large enough to carry a runoff of 1 inch in 24 hours.

Table 3 gives the acreages from which 3/8-inch depth of water will be removed in 24 hours by tile of different sizes laid at grades ranging from 5/8 inch to 12 inches per 100 feet. When 1/2-inch runoff is to be removed, use three-fourths of the acreage given in the table. If surface inlets admit large quantities of water, the tile may give drainage to only a third of the area stated in the table.

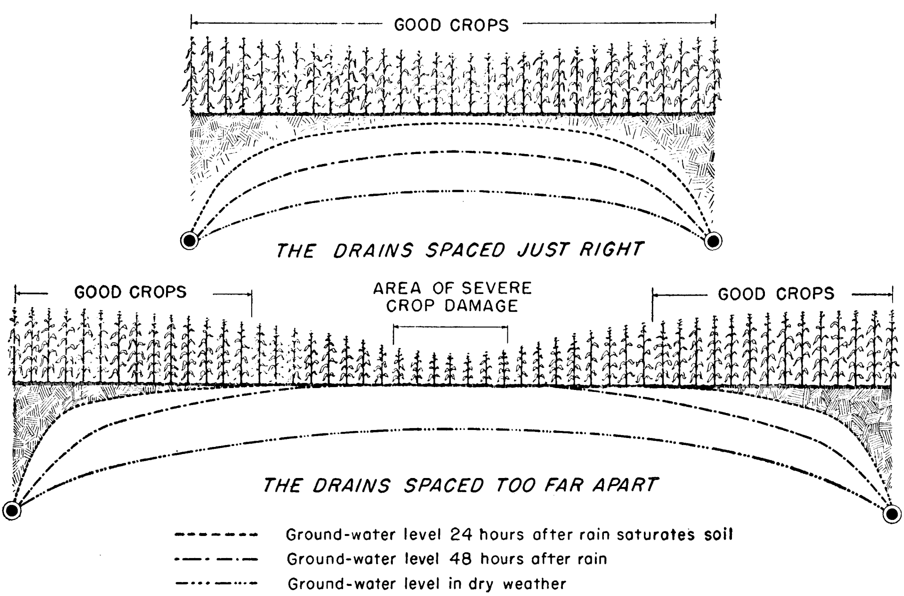

Figure 21.—**How spacing of tile drains affects ground-water level and crop damage.**

TABLE 3.—*Areas from which ⅜-inch depth of water can be drained by tile in 24 hours*

(From Yarnell formula, $V=138\ R^{2/3}\ S^{1/2}$)

Size of tile (inches)	Fall per 100 feet							
	⅝ inch (0.05 foot)	1¼ inches (0.1 foot)	2⅜ inches (0.2 foot)	3⅝ inches (0.3 foot)	4¾ inches (0.4 foot)	6 inches (0.5 foot)	9 inches (0.75 foot)	12 inches (1 foot)
	Acres	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*
4	....	4	6	8	9	10	12	14
5	6	8	11	14	16	18	22	26
6	9	13	19	23	27	30	36	42
8	20	29	41	49	57	64	79	91
10	37	52	74	90	104	117	143	165
12	60	85	120	147	170	189	233	268

Grades for Tile Drains

Experience shows that there are minimum grades at which drains of small-size tile give satisfactory service, and also limits to the lengths that will be satisfactory at those grades.

Table 4 shows the least grades recommended for 4-inch to 6-inch tile, and the greatest lengths to be used with those grades. With any size of tile, avoid flatter grades than 0.05 foot per 100 feet, if possible.

The steepest grade for tile *mains* constructed with farm drain tile should not exceed 2 feet per 100 feet. On steeper grades, bell-type tile (sewer pipe) with sealed joints should be used. If you greatly reduce the grade of a tile main at any point you will need to protect the drain by a pressure-relief well (p. 34).

TABLE 4.—*Maximum length of tile lines at minimum grade*

Size of tile (inches)	Minimum grade per 100 feet	Maximum length
	Foot	*Feet*
4	0. 10	1, 300
5	. 07	2, 000
6	. 05	3, 000

Selecting Tile

Drain tile should be circular in cross section and approximately straight. The inside should be smooth, and the ends should be regular and smooth enough to permit making close joints with spaces of not more than ⅛ inch between tiles. Tile smaller than 10 inches in diameter are commonly 12 inches long; larger tile may be up to 30 inches long, according to the diameter.

Good tile should be free from visible grains or masses of lime or other minerals that cause slaking or breaking down. A broken surface should show a uniform structure throughout. A tile should be free from chips or cracks that would decrease its strength, and when dry it should give a clear ring when stood on end and tapped with a light hammer.

Tile used in underdrains must be strong enough to withstand the pres-

sure that will be put on it. Locating and replacing broken tile in a drain is difficult and costly. The tile should also be resistant to the action of any chemical in the soil and in the water that flows through it. Breaking down by chemical action may even require replacing the whole drain with new and better materials.

The American Society for Testing Materials has prepared specifications for drain tile. In buying tile, you will do well to make clear in the contract that the tile furnished must meet those specifications. Specifications cover clay tile and also concrete tile.

Clay drain tile is classified as either common or vitrified. Common tile is made from common brick clay, the kind that when well-burned makes a good-quality building brick. Vitrified tile is made of ground shale or of a high-grade clay, frequently mixed with common clay. Some is salt-glazed. Vitrified tile is stronger and less porous than common tile and usually is more resistant to frost action. Either kind is satisfactory for farm drainage.

Clay tile should be hard burned. Drain tile sold as "porous" usually is not burned enough. Hard-burned tile usually is stronger, more dense, and better able to withstand freezing and thawing. (Any tile more than half full of water will break if reached by heavy frost unless the surrounding earth is frozen enough to support the tile.)

Concrete tile is used widely in the West. When properly made, it is satisfactory in soils free from acids and alkali salts.

Concrete tile must be made of clean sand and gravel—or of crushed hard stone properly sized and free from dust—and portland cement, all thoroughly mixed. Finally, the tile must be cured properly.

To make good concrete tile takes the right equipment and careful supervision by experienced men. For this reason, the making of tile on the farm is not recommended.

Buy concrete tile from a factory that is well equipped and is known to be reliable. Concrete tile to be used in peat soils should meet the requirements for "extra quality" drain tile as specified by the American Society for Testing Materials. Where the soil or the ground water contains either acids or alkali salts, ask advice of your local soil conservation district, the county agricultural agent, or the State college of agriculture.

Constructing Tile Drains

Staking Out Tile Drains

Stake out the drains by setting stakes at 50-foot intervals. At each 50-foot station should be two stakes—a hub or grade stake with its top about at ground level and a guard stake standing a foot or more above ground (fig. 24).

The grade hub is a marker from the top of which all measurements are made. The grade hub, therefore, should be set firmly. The hub elevations should be determined accurately.

The guard stake locates and gives the number of the hub, and on it may be marked the required depth of cut below the top of the hub. Determine this depth by subtracting the elevation of the designed trench bottom from the elevation of the hub.

It is imperative that there be no sags in the completed tile line. Silt is likely to settle in any depression and cause partial or even total clogging of the drain. Therefore, the leveling must be very accurate.

Use an engineer's level where practical and, if trenching is to be done with hand labor, follow the method establishing grade described on pages 25 to 28. The less the fall you allow for the drain, the greater the necessity for accurate work.

Tile Trenching With Machinery

Shortage of labor skilled in laying tile has led to the use of power-operated

***Figure 22.*—Wheel trenching machine in operation. The man at the wheel is controlling the depth of the trench by sighting over the target. The man in the trench is putting the tile in place.**

machines, under contract with a man or company in that business. Some owners of large farms, and groups of farmers in many soil conservation districts, find it economical to buy a trenching machine. This may cost $8,000 to $10,000 and require a trained operator. But the cost of trenching with rented machinery is not greatly different from the cost with hand labor, and the work is completed more rapidly with fewer men.

Power-operated trenching machines are of two types, wheel excavators and endless-chain excavators. The wheel excavator, shown in figure 22 and in the cover illustration, is more common in farm-drainage construction. It has, just behind the excavating wheel, a shoe for giving the trench a smooth, firm, rounded bottom upon which to lay the tile. The machine also has a shield to keep loose dirt from falling into the trench until the tile can be placed, and a chute that lays the tile at the end of the smoothing shoe.

Proper depth to give the drain a uniform grade is obtained by raising and lowering the excavating wheel as the machine travels along the line of the drain. The machine operator moves levers to keep the sight bar in line with targets set ahead. These targets are long stakes or rods driven vertically near the grade hubs. Each has a level cross bar at a height above the grade line equal to that of the sight bar on the machine.

There are several special trenching plows that may be helpful in tile-drain construction if a power-operated machine is not available.

Hand Trenching

The tools most commonly used in trenching and laying tile by hand are tile spades, shovels, drain scoops, tile hooks, and gage sticks (fig. 23).

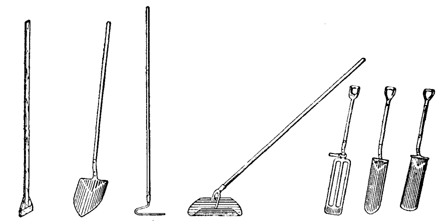

***Figure 23.*—Hand tools for tile-drain construction.**

The tile spades are of two kinds—solid and open—with blades 16 to 22 inches long. The 18-inch and 20-inch sizes are used most. The open spade is used in mucky or sticky soils.

The shovel is of the ordinary long-handled, round-nosed type.

The drain scoop is semicylindrical in shape and is fitted with a long handle. It is made in sizes to fit 4-inch to 8-inch tile.

The tile hook is made of ½-inch round iron—one side 9 inches and the other 4 inches long—fastened to an ordinary rake handle.

The gage stick is a straight stick 1 by 2 inches in cross section and 5 or 6 feet long to suit the method of establishing grade. A braced T-piece on the bottom aids in setting the gage vertical.

Establishing Grade

The best method of establishing grade for hand trenching when the workmen are inexperienced is probably that of gage and line (fig. 24). This consists of stretching a cord at a uniform height above the bottom of the trench to be dug and measuring down from it with a gage stick. The cord should be placed high enough so that it will not interfere with the men working in the trench.

To set the grade cord at the right elevation, at each station set two strong stakes upright near each grade hub, one on each side of the drain line. To these uprights fasten a cross bar, at a height above the hub equal to the difference between the length of the gage stick and the depth of cut at that station. Use a carpenter's level to set the cross bar level.

A convenient way to fasten the cross bar to the uprights is by clamps. Similar cross bars should be set at three or more consecutive stations. If the fall of the drain is uniform, you can detect any error in setting the cross bars by sighting over them.

Next, across the tops of the bars, over the center line of the trench, stretch a light strong cord (preferably fishline). This grade cord must be kept taut. Otherwise there will be sags in the tile line that will very likely cause trouble later.

The trench bottom is at correct grade when the gage stick is upright in the trench and its top just touches the grade cord. The bottom of the gage stick must be kept clean; any adhering dirt will result in incorrect grade.

A slightly different method of obtaining correct grade, widely used by experienced tile layers, is shown in figure 25.

Since trench diggers work backward up the drain line, it is more convenient for them to sight down rather than up the completed trench. So, where you can do it, in starting from the outlet or from a point where the grade changes, it is well to set extra targets down the grade, lined in with those above. The same procedure will often help where the drain makes long curves.

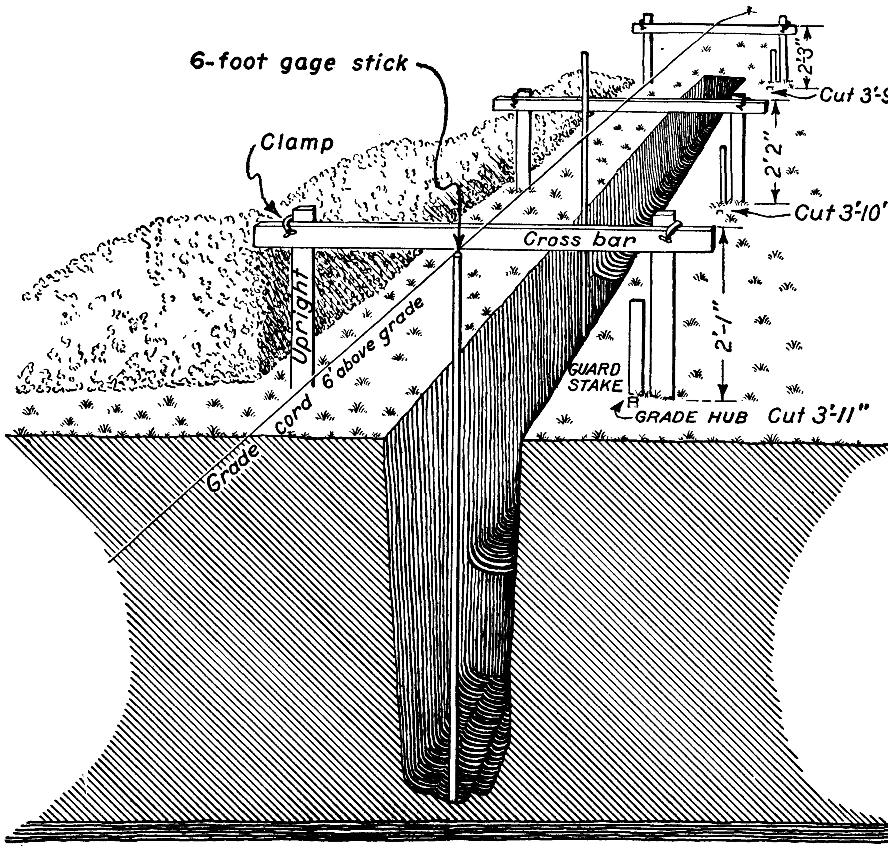

Figure 24.—**Gage-and-line method of establishing grade for a tile drain. A cut of 3 feet 11 inches is indicated at the hub in the first station. Subtracting this cut from the length of the gage stick (6 feet), the difference of 2 feet 1 inch is the height for setting the top of the cross bar above the hub. The gage stick at the first station shows that the trench has been dug to the correct grade elevation at that point. The gage stick at the second station shows that more digging is required for the needed cut of 3 feet 10 inches.**

Digging the Trench

Begin digging the trench at the outlet and proceed upgrade. This permits any water that gets into the trench to flow away instead of collecting to make the trench bottom soft.

You must lay the drain in straight lines and smooth curves if it is to be most effective and least likely to become obstructed. To do this, a guide must be used in the trenching. A guide line or rope is stretched along the ground about a foot to one side of the side of the grade hubs, making smooth curves at all bends. Then the edge of the trench is marked off along this line with a spade. If the top spading is done to imperfect line, it is practically impossible to smooth up the line on later spadings.

For small tile, you usually dig trenches 12 to 15 inches wide, with the sides practically vertical. Dig them with tile spades to within 1 or 2 inches of grade; then clean out the bottom

to the correct grade with a tile scoop. Most tile trenches are 2 or 3 spade blades deep.

The tile spade is somewhat different from the ordinary spade or shovel used in farm work. In digging with it, you should not attempt to take a thick bite for the spading cannot be loosened readily from the side of the trench. Moreover, the earth on the spade will shatter and too much of it will crumble into the trench.

The correct method of using the tile spade is shown in figure 26. When the trench has been dug to within an inch or two of grade elevation, the loose crumbs of soil left by the tile spade must be taken out.

To finish grade, the workman stands in the trench ahead of the tile and draws the scoop toward him, leaving the trench bottom smooth and rounded to fit the lower part of the tile.

Take great care to cut the bottom of the trench accurately to grade. If the trench is cut below grade at any place,

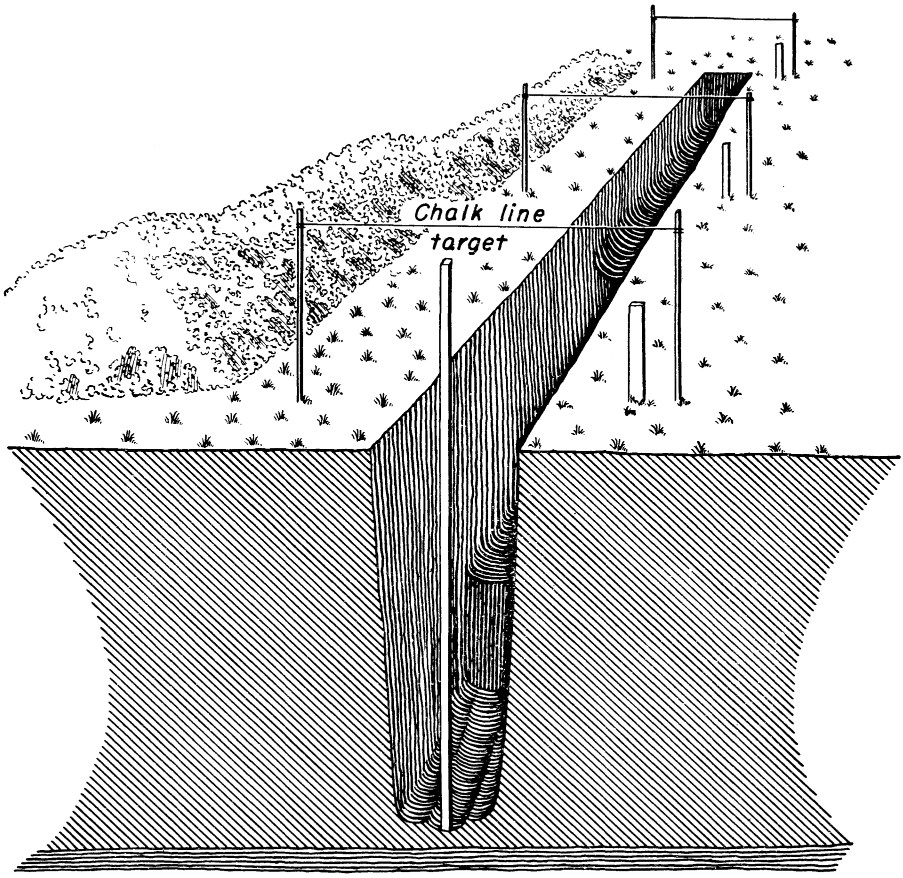

***Figure 25.*—Target method of establishing grade for a tile drain. Stretch three or more white chalk lines across the trench between upright stakes. Their height above the hubs should be the difference between the depth of cut and the length of the gage stick (usually 5 feet). Sight over the chalk lines and the top of the gage stick. If they line up, the trench is at grade. If the top of the gage stick is above the line of sight established by the chalk lines, the trench is not deep enough; if it is below, the trench is too deep.**

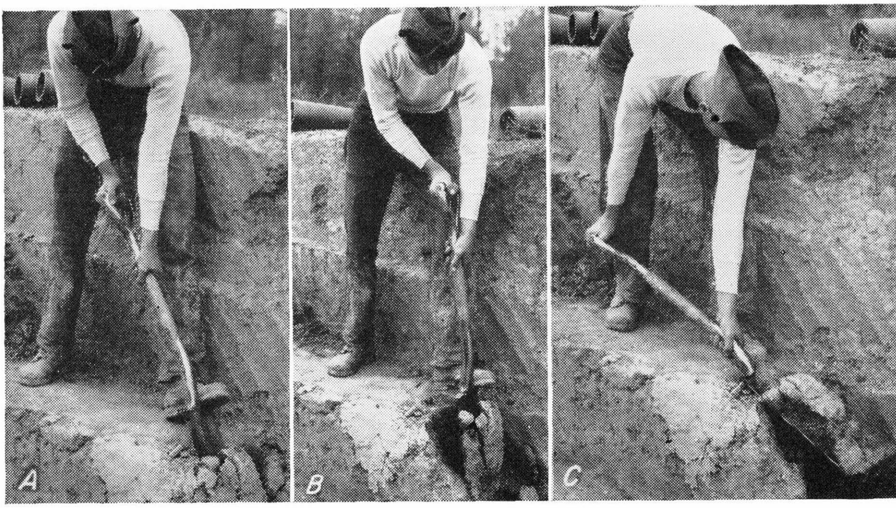

***Figure 26.*—How to use a tiling spade: *A*, Drive blade obliquely for three-fourths its length; *B*, push handle forward and drive blade vertically to its full length; *C*, pull handle back and lift loosened spade load from trench.**

the low spot should be filled with well-pulverized soil and thoroughly tamped, and the scoop used again.

Be sure that the tile scoop used is of suitable size for the tile being laid. The 5-inch size meets most of the requirements for ordinary farm work. The round-nosed shovel is commonly used for finishing grades for tile larger than 8-inch. Where it is used, the bottom of the trench should be finished to fit the bottom eighth of the tile.

Laying the Tile

Like trenching, laying the tile should begin at the lower end or outlet and progress up grade, following closely the excavation of the trench. In placing tiles, turn them until they fit closely together. If a tile is crooked or the ends are irregular, turn it until it fits tightly at the top and the open space is left at the bottom. Where a crack or opening of as much as $\frac{1}{4}$ inch must be left at the top or sides, cover it with pieces of broken tile, a strip of roofing paper, or, in some sandy soils, cement mortar.

Some factories now are making tile so uniform in cross section and with ends so regular that the tile can be fitted very closely together and there is little space for the water to enter the drain. Where such tiles are used in heavy soils, they should be spaced about $\frac{1}{16}$ to $\frac{1}{8}$ inch apart. But where fine sand is likely to be washed into the drain, the tile should be fitted closely.

Tile up to 6 inches in diameter can be placed with a tile hook by a man on the trench bank. Or it can be placed by hand by the man who is finishing the trench with the tile scoop. Results are usually best if the man using the tile scoop, working backward up the trench, lays the tile as fast as he finishes the grade.

In a wet, soft trench it may be advisable to lay the tile on plank bedded at grade. Through saturated fine sand or sandy loam it may be necessary to wrap the joints with cloth or roofing paper to prevent soil from washing into the drain. In laying tile through quicksand you need the help of a man experienced in such work.

All tile that are cracked, soft, or poorly shaped should be laid aside. Unless there is an excessive number they will not be wasted, because you will need broken tile to patch junctions and wide joints.

It is very important that the tile be laid and blinded (p. 30) as soon as the trench is completed to grade. Otherwise, banks may cave and the bottom may soften. To prevent dirt getting in, the upper end of the tile line should be closed whenever workmen leave the job. When a line is completed its upper end should be closed with a brick or stone or pieces of broken tile.

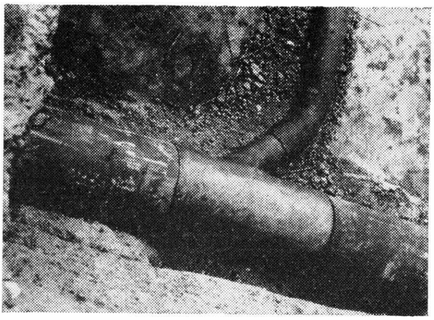

***Figure 27.*—A well-made junction of small lateral with larger main tile drain.**

Making Junctions and Curves

Junctions between laterals and main tile drains should be made with Y's (fig. 27), not with T's or elbows. Practically all tile factories make junction tile. Buy these if possible. If you cannot get Y's, you can make junctions by cutting and fitting straight tile. When you do this, take care to prevent the branch tile from projecting into the main. Unless lack of fall prevents, there should be a drop from the branch into the main. You can assure this drop by turning the Y slightly in its bed so as to elevate the branch (fig. 28).

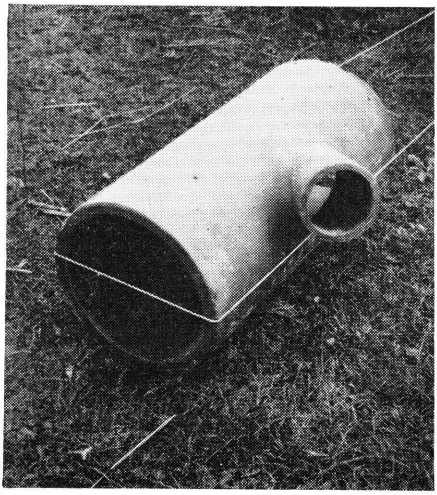

***Figure 28.*—A junction tile turned so that the branch is above the middle, to give fall from the lateral into the main drain. The string marks the middle.**

Be sure that changes in direction are made by curves and not by sharp angles. Keep the curves regular, with the outer side of the joints covered with pieces of broken tile (fig. 29). In sandy soils, you can chip off the

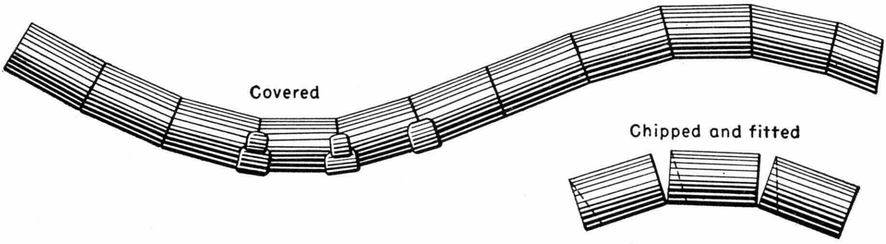

***Figure 29.*—Curves in tile lines.**

ends of the tiles on the inner side of the curve by catching the edge of the tile between the jaws of a monkey wrench and bearing down on the handle.

Blinding the Tile

On the day that the tile are laid they should be covered with loose earth to a depth of 4 to 6 inches, to hold them in position. This work is called blinding the tile. A workman stands astride the trench and shaves earth from the sides with a tiling spade.

Work the earth under the sides of the tile to give them support and prevent displacement when the trench is backfilled. But take great care not to compact the earth about the joints, for that would be likely to keep water from getting into the drain.

In tight soils you often get better results by taking earth from the upper edges of the trench. Topsoil usually is looser and contains organic matter and therefore helps percolation into the tile drain. Putting topsoil around the joints may prevent the soil's cementing the tile joints, which would keep water out of the drain. If you can get them at a reasonable cost, organic materials such as straw or pine needles are good in both tight and sandy soils.

In tight toils, gravel is good if you can get it at reasonable cost. It is also good for filling the trenches to within about a foot of ground surface. The upper foot should be filled with soil.

Backfilling the Trenches

Trenches should be filled soon after the tile are blinded. You can do this readily with a farm tractor and a homemade bulldozer. If you use horses, a scoop or V-drag can do the job. Usually two rounds are enough to backfill the trench. A scraper made from a 2- by 12-inch plank about 4 feet long can be used to advantage for many trenches. With this, the horses work at right angles to the trench, scraping in the earth piled on the farther side. If a scraper, a tractor and bulldozer, or a road grader is used, it will save work in backfilling if all the earth thrown out in digging the trench is on one side, rather than part on each side.

Protecting the Outlet

Failure to protect the outlet end is one of the most common causes of tile drains failing to work well. The outlet should be protected against washing or eroding of the ditchbank. Also, trampling livestock can force tile out of position; or animals may nest or become lodged in the tile and block the flow of water.

You can get good protection for a tile outlet with a reinforced concrete headwall or bulkhead (fig. 30). In front it should extend from the ground surface to at least 1½ feet below the bottom of the ditch. A solid foundation is necessary to prevent undermining of the structure and heaving from frost action. The headwall should be set in line with the top of the ditchbank. Wing walls should be constructed at right angles to the headwall with their tops about level with the slope of the ditchbank. An apron or floor should be constructed between the wing walls to prevent the water from the tile undermining the headwall. For 10 to 15 feet from the headwall, the drain should be either vitrified bell-type tile (sewer pipe) with firmly cemented joints or a length of metal pipe. Ordinarily, surface water which follows the depression over the tile line should be diverted so as not to discharge over or near the headwall.

In many places you can protect the tile outlet merely by using a 15- to 20-foot length of strong metal pipe for the end section of the line. If not likely to be displaced by ice or floating debris, it should stick out through the bank of the outlet ditch (fig. 30) far enough so that the flow from it will fall

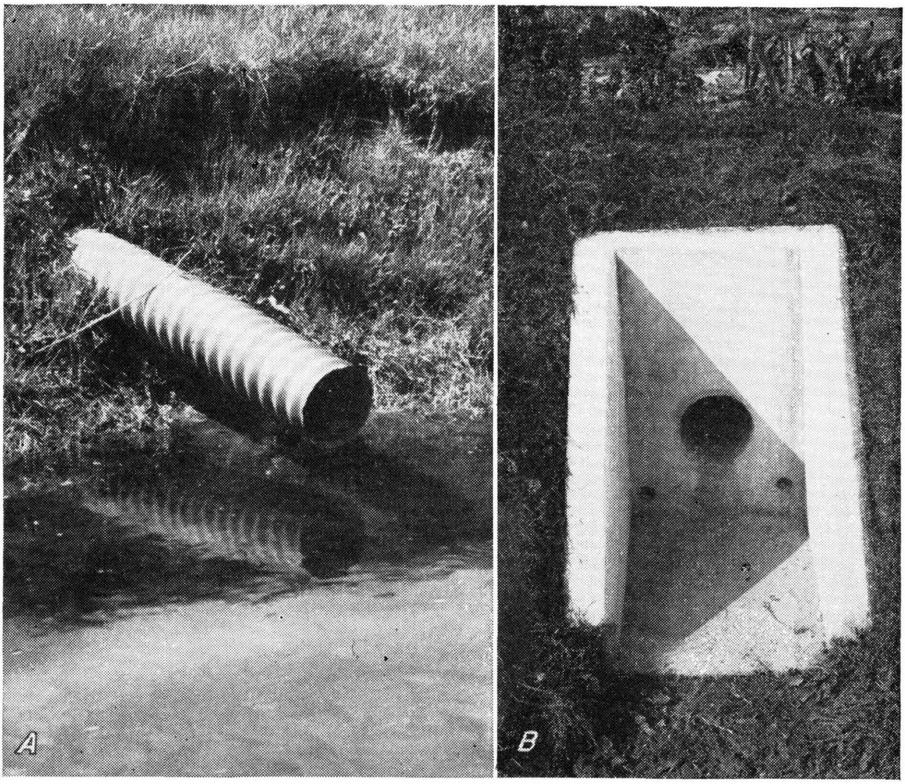

***Figure 30.*—Outlet protection for tile drains: *A*, Corrugated metal pipe that will empty into the drainage ditch without eroding the ditchbank; *B*, reinforced concrete headwall, with wing walls and apron.**

beyond the slope of the ditchbank. Otherwise it should not stick out, and you should protect the bank slope under it against erosion by making a substantial pavement.

If the pipe sticks out, it should be pointed to angle downstream, to reduce interference with the flow in the ditch.

The pipe should be about 2 inches larger than the tile discharging through it, so it can be slipped over the last tile for about 6 inches. This joint should be cemented tight, to prevent any earth from being washed into the drain.

To prevent burrowing animals such as muskrats and rabbits from entering the tile, hang a screen or gate over the end of the drain. Use the swinging type, because one rigidly fixed will catch trash washed down the drain and obstruct the outflow. Figure 31 shows such gates easily made of heavy galvanized sheet metal.

The gate should extend well beyond the sides of the drain opening, except that when fastened to the end of a pipe the top of the sheet should be trimmed to permit easy opening. Folding back the edges will make the sheet more rigid. The wire links supporting the gate should be large and loose, for freedom of movement. Heavy wires fastened to the end of the pipe about 1½ inches apart, also make an effective screen. Such screens must be cleaned annually.

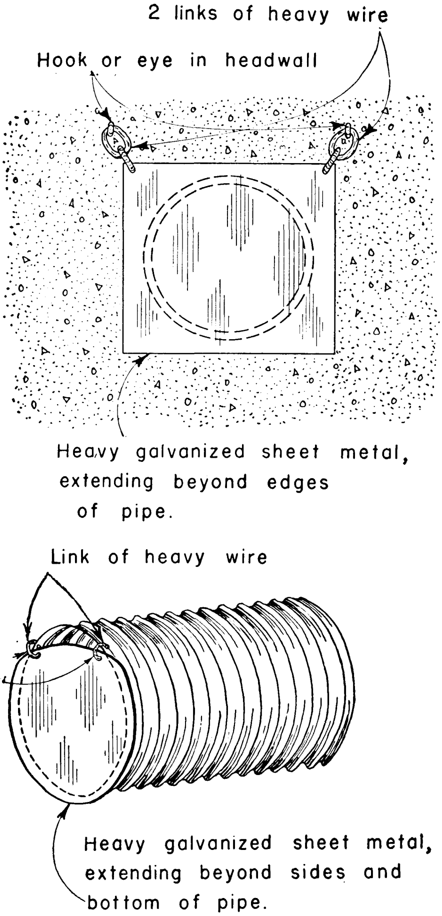

***Figure 31.*—Simple sheet-metal gate to keep small animals out of tile drains: Top, attached to a headwall outlet; bottom, attached to a corrugated pipe outlet.**

Surface Inlets and Silt Wells

In some tight soils surface water collects in low spots and stands until it "scalds" the crop. Here you may need a surface inlet to let the standing water directly into your tile drain. Surface water usually carries a good deal of fine sand and trash. For this reason a good surface inlet should include some means of trapping this solid material before it gets into the tile. Figure 32 shows two plans for such inlets. They are planned so that flow will stop before the silt can be discharged into the tile line.

If tile drains are carefully constructed, silt wells are seldom necessary except where there is a surface inlet. But, a silt well may be needed where the grade of a tile line changes abruptly. When the grade decreases, the speed of the water decreases. And when the speed of water decreases, its capacity for carrying suspended soil also decreases. In other words, where tile flattens out suddenly there is danger it will clog up. This danger is especially great if the soil contains much fine sand and silt—the kind of silt in a silty clay loam soil.

Two or more lengths of sewer pipe set on a concrete base make a satisfactory silt well (fig. 33). Or you can build one of concrete (fig. 34). Where the silt well would interfere with cultivation, sink the top a foot and a half or so below the ground surface and cover it with soil. In this case, make a record of the location so you can find it easily later. Also, a buried well should have a solid cover that can be removed without too much trouble when the well needs cleaning (fig. 34).

Silt wells can also serve as junction boxes where two or more tile lines come together (fig. 34).

Where there is only a little surface water, you can usually handle it satisfactorily through a "blind inlet" (fig. 35). You can make one by filling a small section of a trench with stones, broken brick or tile, or gravel. The filler should be graded upward from coarse to fine. Use still finer material for the top 12 to 18 inches. In cultivated fields, use porous soil. Elsewhere pea gravel or coarse sand is satisfactory.

Check the inlet now and then. Whenever enough trash or sediment collects to keep the water from draining through quickly, the top layer should be shoveled out and new put in.

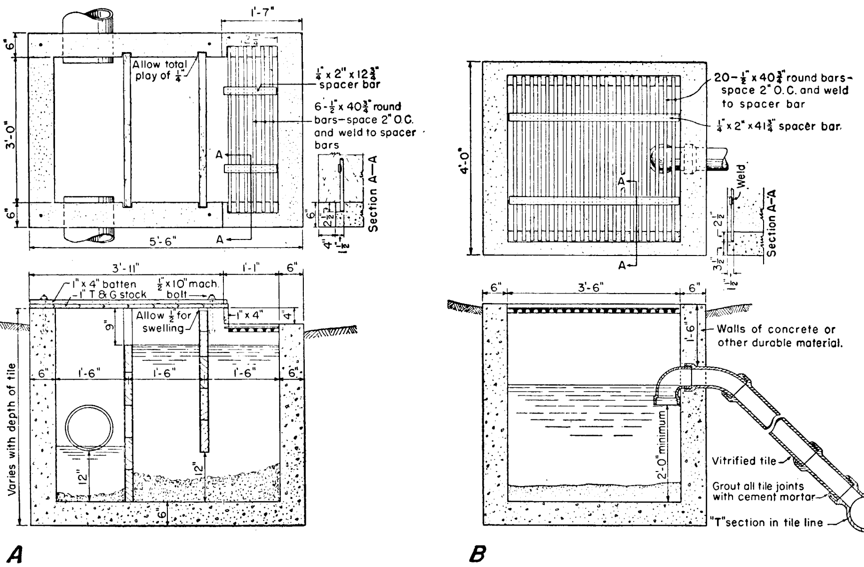

Figure 32.—*A,* An engineer's drawing of a surface inlet with removable baffles for ease in cleaning. When the well fills with sand and silt, flow into tile line is automatically shut off. *B,* A surface inlet with bell-and-spigot pipe outlet.

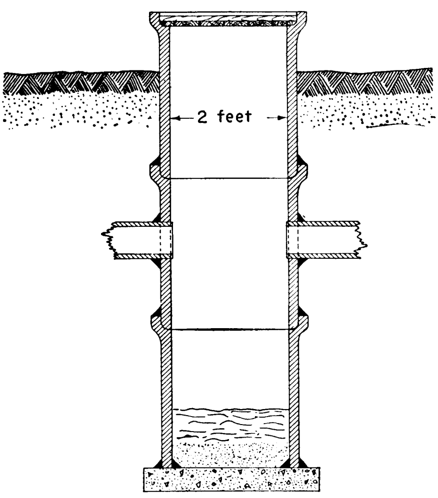

Figure 33.—A silt well made with sewer pipe. Since it has an open top it also serves as a "relief well." Like the concrete silt well in figure 34, it can serve also as a junction box where two or more tile lines come together.

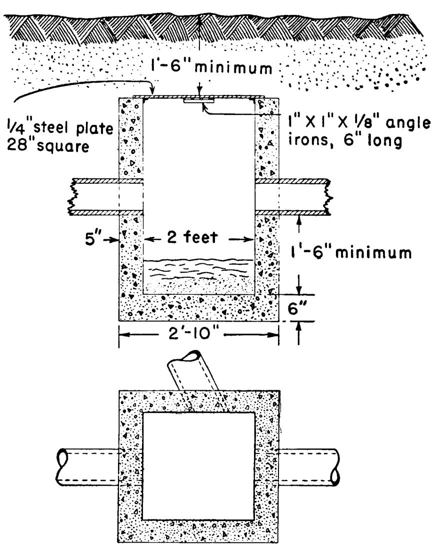

Figure 34.—A silt well made of concrete and sunk below plow depth so as not to interfere with cultivation. Silt wells can also serve as junction boxes, as shown in the cross section that is the lower part of the drawing.

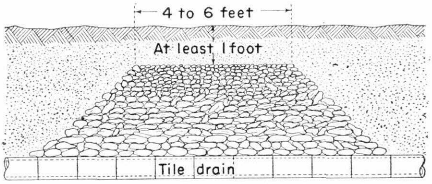

Figure 35.—**A blind inlet made by digging out a wet spot over tile and filling it with cobblestones, broken tile, and gravel graded upward from coarse to fine. In cropland the top 12 inches should be porous soil.**

Relief Wells

Silt wells with open tops also serve as "relief wells" (fig. 33). You need a relief well wherever a tile main flattens out and the tile in the flatter part is not large enough to take care of the resulting pressure. If the water pressure in the tile is greater than that in the soil, it forces water out through the joints. This washes soil from around the drain and permits the tile to get out of place.

Usually you need a relief well if the grade flattens by more than 1 percent. Figure 36 shows one made of sewer pipe. For added protection, a section of sewer pipe with closed joints may be needed in the tile line.

A relief well should be supported by a base of concrete if the soil on which it is built is soft when saturated.

Relief wells are best located at fence lines and field borders (fig. 37). There they interfere least with farming and are in least danger from farm machinery.

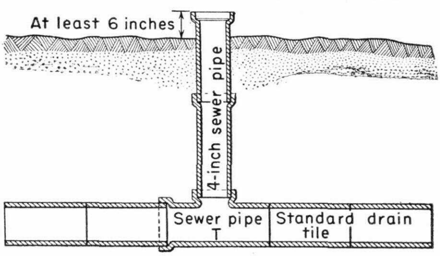

Figure 36.—**A pressure relief well made of sewer pipe.**

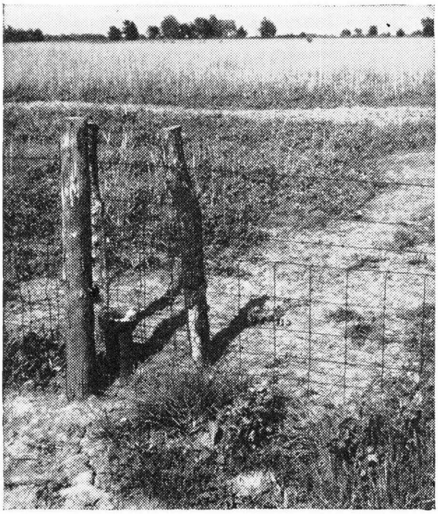

Figure 37.—**A relief well located at a fence line where it will not get in the way of farming operations and will not be run over by farm machinery. The posts give added protection.**

Drains Obstructed by Tree Roots

Roots of trees growing near tile drains may enter them and obstruct flow. This is most apt to happen where drains are fed by springs and carry water in dry seasons. The roots enter the drains to get moisture. Masses of roots sometimes grow until they completely fill the tile. Where you have reason to expect this difficulty, use sewer pipe or bell-and-spigot tile and cement the joints tight. As a general practice, destroy all willows and other water-loving trees growing within 50 feet of your tile drain.

Cost of Tile Drainage

The cost of tile drainage varies greatly. The major items are: (1) Number and size of tile needed, (2) price of tile, (3) transportation from factory to point of use, and (4) labor of trenching, laying, and backfilling. Lesser items include cost of structures, such as outlet protection and surface inlets, and planning and supervision.

Prices of both materials and labor vary with location and with time. According to prices prevailing in the Central States in 1952, rough estimates give the cost of 4-inch, 5-inch, and 6-inch tile drains as 20 to 30 cents per foot for the completed drain. This includes all costs. Factory prices for tile are given in table 5.

Most factories sell tile by the thousand feet. The amount needed per acre for lateral drains of different spacings is shown in the following tabulation. The amount needed for mains depends on the arrangement of the drains. The sizes are determined by the method stated on pages 21 and 22.

Distance between laterals (feet):	*Feet of tile required per acre*
40	1,089
45	968
50	872
55	792
60	726
65	670
70	623
75	581
80	545
85	513
90	484
95	459
100	436
150	291
200	218

TABLE 5.—*Weights and prices of drain tile in the Middle West in 1952*

Size of tile (inches)	Weight per foot	Price per 1,000 feet at factory in carload lots
	Pounds	*Dollars*
4	6	60 to 65.
5	9	90 to 100.
6	12	120 to 130.
8	18	200 to 220.
10	27	320 to 340.
12	36	400 to 440.

Digging the trench and laying and blinding the tile are generally considered as one operation. It is usually done by contract at an agreed price per rod or per 100 feet. This price is affected by the nature of the soil, the depth of the drain, and the size of the tile. The usual cost (1952) of laying 4-inch, 5-inch, or 6-inch tile 3 feet deep or less ranges from $1.00 and $1.50 per rod. Installing 8-inch tile 3 feet deep generally costs $3.50 to $4.50 per rod. As a rule, the price increases rather rapidly with the depth.

Backfilling the trenches usually is done by the farmer or his regularly hired labor. It seldom is an item of cash expenditure.

The cost of the lesser items mentioned must be estimated individually for each job, according to the number and size of the outlet and inlet structures, the complexity of the design, and the conditions of work. At most, they constitute a small part of the total.

Where a random system of intercepting drains will suffice, the cost of tile drainage may not be more than $25 to $30 per acre, but usually the total cost will be greater than this. For a complete system the cost will depend largely on the spacing of the laterals. With drains 50 feet apart the total cost may be $175 to $200 per acre, and with drains 80 feet apart the cost may be $100 to $125 per acre. With such high costs the value of the land and crop returns need to be carefully considered.

Any farmer contemplating the installation of a drainage system should base his estimate of the cost on prices of materials and labor prevailing when and where the work is to be done.

Vertical Drainage

By vertical drainage is meant the disposal of drainage water through wells into a porous layer of earth or an open-rock formation. Such layer or formation must be capable of taking large volumes of water rapidly. It must, of course, have outlets lower than the land to be drained. Such a substratum, at a depth that can be reached without prohibitive cost, is rare. Usually there

is no way of determining in advance that it has enough capacity as a drainage outlet to be permanently effective. In the limestone regions with their "sink holes" such wells frequently can be used to advantage if outlet into natural or artificial surface water courses is not easily obtained. In general, however, the possibilities of vertical drainage are very limited.

Drainage wells must be lined, except wells through rock, to keep earth from falling in and clogging them. Also, the tops must be protected against entrance of trash and sediment. The cost of many such wells has been $100 to $200 per acre. This is much greater than the cost of most surface outlets. Therefore the installation of drainage wells is not recommended where a surface outlet can be obtained at reasonable cost, except in those rare places where it is certain that vertical drainage is feasible.

Drainage Records

Keep a permanent record of the locations, depths, and sizes of all drains. Be sure to preserve all maps, plans, and profiles of the system installed, and all notes relating to it. Some of those most experienced in farm drainage recommend that a drainage map of the farm, with full information concerning the drains as finally constructed, be recorded in the land records of the county.

Where your tile line crosses or ends at a fence, farm road, or other permanent line, drive in an iron stake or piece of pipe so that the drain can be located easily at any future time. You will appreciate this marker when you wish to extend or repair drains, or to add branches.

Maintenance of Farm Drains

Farmers' Bulletin 2047, Maintaining Drainage Systems, gives many suggestions for the maintenance of farm drains and also drainage enterprises. Here are a few of the things you should keep in mind to keep your farm drains working efficiently.

First of all, any drain that is to work efficiently must be kept clean.

Make frequent inspection of open ditches and outlet channels and remove all weeds, briars, willows, silt, trash, or refuse of any kind that obstructs the flow of water. Frequent inspection keeps maintenance costs comparatively small. But if you allow ditches to deteriorate, the cost of repairing or redigging them may equal the original cost.

On outlet ditches, a good grass sod will reduce maintenance problems. Pasturing such ditches, where practicable, is an effective and economical way of controlling growth, but stock should not be allowed on the ditches when the banks are saturated. In many places you will find it practical to mow the ditches, or to cut and burn the weed growth.

The important thing is to keep the ditch free of anything that will obstruct the flow of water in the channel. You can often remove silt bars that form in an outlet ditch with dynamite or with slip scrapers.

Small V-shaped field ditches can usually be maintained in satisfactory shape by plowing. If such ditches are planted to grass, keep them mowed, and use the grass for hay.

Tile drains with good outlets, if properly constructed, seldom become clogged. Nevertheless, it is advisable to inspect the tile system at least once or twice a year by walking along the tile lines. The condition of the soil along a drain a few days after a heavy rain indicates how the drain is working. Wet spots show that water is not being carried off (fig. 38). A hole or cave-in above a tile line indicates that a tile has been either broken or displaced. When this occurs, take immediate steps to repair the line. Otherwise the whole drain above the break may become filled with silt that makes it necessary to replace that part of the line.

***Figure 38.*—The wet spot is a warning that the tile drain is not working. If this happens on your farm, you should check immediately to find the cause and repair the drain. Otherwise the trouble may spread.**

Crop rotations and methods of cultivation that maintain a good soil structure help keep tile drains working. This is especially true with heavy soils. The continued growing of clean-tilled crops breaks down the soil structure until water cannot percolate to the drains rapidly enough.

Many farmers in the old Black Swamp of northwestern Ohio had good drainage when they placed their tile 6 rods apart soon after the land was cleared. After the land had been cropped principally to row crops for a number of years, many of them installed new tile lines midway between the original lines. They had little or no better drainage from their land with tile lines 3 rods apart than they had originally with lines 6 rods apart. The continuous cropping had broken down the soil structure and water could not get to the tile rapidly.

Farmers have found by experience that they can improve drainage by use of deep-rooted legumes such as alfalfa and sweetclover. A conservation rotation, cover crops, and other soil-improving practices are necessary to maintain good farm drainage.

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